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THE Marquardt CORPORATION

VAN NUYS, CALIFORNIA

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(TITLE -- UNCLASSIFIED)

TENSILE AND CREEP PROPERTIES OF 0.010 AND 0.020-INCH RENE' 41 ALLOY SHEET FROM ROOM TEMPERATURE TO 2000°F

UNCLASSIFIED

(Title -- Unclassified)

TENSILE AND CREEP PROPERTIES OF 0.010 AND 0.050-INCH RENE' 41 ALLOY SHEET FROM ROOM TEMPERATURE TO 2000° F

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Project 281

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I. SUMMARY

A materials testing program was conducted to evaluate the important mechanical properties of Rene' 41 alloy sheet. Two thicknesses of sheet (0.010 and 0.050 inch) were used throughout the program. In addition, several tests were conducted using two different solution heat treatments (2150°F versus 1950°F) to determine their effect on mechanical properties.

Tensile properties were investigated from room temperature to 2000°F. Strain rate sensitivity of tensile properties was also investigated. Creep and rupture properties at temperatures from 1400° to 1800°F were determined for short times of 1 to 1000 seconds and for longer times of 10 to 100 hours.

II. INTRODUCTION

Rene' 41 alloy sheet has received extensive interest and usage from the aerospace industries because of its excellent combination of mechanical properties, oxidation resistance, and reasonable ease of fabrication. This test program was initiated because several specialized mechanical properties that could not be obtained from vendor literature were required by Marquardt designers, for example, the strain rate sensitivity of tensile properties. Therefore, a program was initiated for testing the two most widely used thicknesses of Rene' 41 sheet: 0.010 and 0.050 inch. An additional reason for selecting these two thicknesses was that previous work on superalloys had shown important differences in mechanical properties between these thicknesses.

Two vendor-recommended heat treatments for Rene' 41 alloy sheet exist. One to yield maximum creep properties (2150°F solution anneal) and another for maximum elevated temperature tensile properties (1950°F solution anneal). Both heat treatments were investigated for the two thicknesses of material utilized in the program.

III. OBJECTIVES

A. Tensile Properties

Tensile properties were determined at selected temperatures ranging from room temperature to 2000°F on two thicknesses of Rene' 41 alloy sheet and for two different solution heat treatment temperatures. The effect of various tensile test strain rates on room and elevated temperature tensile properties was determined.

B. Creep Properties

The 1600°, 1800°, and 2000°F creep and rupture data were determined for 0.050-inch thick Rene' 41 alloy sheet solution annealed at 1950°F. The 1400°, 1600°, 1700°, and 1800°F creep and rupture data were determined on 0.050-inch Rene' 41 alloy sheet solution annealed at 2150°F.

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IV. MATERIAL AND HEAT TREATMENTS

The chemical analyses of the three heats of Rene' 41 alloy sheet used in this investigation are listed in Table I. Table I also contains the allowable ranges for chemical composition of Rene' 41 alloy sheet from the General Electric Company specification. All heats of material used in this investigation met the specification. The heat treatments recommended by the General Electric Company are listed in Table II, along with the material heat numbers, thicknesses, and heat treatments used in this investigation.

V. EXPERIMENTAL PROCEDURES AND RESULTS

A. Tensile Properties

The tensile specimens which were used had a 0.500-inch width of reduced section and a 2-inch gage length. All room and elevated temperature tensile tests were conducted on the Marquardt TM-1 elevated temperature test machine. Figure 1 is a photograph of this machine and its peripheral equipment. Elevated temperatures are obtained on this machine by resistance heating of the specimen. Three pairs of 36 gage wire thermocouples are welded to the specimen. One thermocouple is used for electronic feedback control of the temperature and the other two thermocouples are used to check and record the thermal gradient along the 2-inch gage length. Strain rates are electronically controlled with feedback from the linear transducer of the extensometer.

The results of tensile tests from room temperature to 2000°F on 0.010 and 0.050-inch thick Rene' 41 alloy sheet for three different strain rates are reported in Tables TTT through TX. Table X contains a comparison of yield strength with strain rate. Stress-strain curves to beyond 0.2% yield strength for temperatures from room temperature to 2000°F are presented in Figures 2 through 4. The variation of proportional limit, 0.2% yield strength, and ultimate tensile strength with strain rate and temperature are presented in Figures 5 through 7, respectively. Figure 8 illustrates the variation of ultimate tensile strength with temperature and for both thicknesses and heat treatments used in this investigation.

B. Creep Properties

The results of creep tests at 1400°, 1600°, 1800° and 2000°F for two heat treatments on 0.050-inch thick Rene' 41 alloy sheet are tabulated in Tables XI through XIV. These results are shown graphically in Figures 9 through 15.

VI. DISCUSSION

A. Tensile Properties

For 0.050 inch thick Rene' 41 alloy sheet solution heat treated at 1950°F, the proportional limit and yield strength become strain rate sensitive above 1200°F. For 0.010 and 0.050-inch Rene' 41 alloy sheet given a solution heat treatment at 2150°F, the strain rate sensitivity of proportional limit and yield strength does not begin until 1400°F. For 0.050-inch Rene' 41 alloy sheet, the

tensile strength becomes strain rate sensitive above 1450°F. At temperatures in the 1500°F to 2000°F range, very severe drops in strength can result from using slow strain rates. For example, the yield strength of 0.050-inch Rene' 41 alloy sheet solution heat treated at 1950°F is 107.5 Ksi at 1600°F using a 0.1 in./in./sec strain rate. With a 0.00001 in./in./sec strain rate, the yield strength drops to 56.0 Ksi. Other comparisons of strain rate sensitivity are given in Table X. As expected, the 1950°F solution heat treat temperature gives the 0.050-inch material superior ultimate tensile strength at all temperatures, as compared to a 2150°F solution heat treat temperature. The ultimate tensile strength of 0.010-inch thick Rene' 41 alloy sheet solution annealed at 2150°F is decidedly inferior to that of the 0.050-inch material for the same heat treatment. This behavior is illustrated in Figure 8.

TABLE I

CHEMICAL COMPOSITION OF THREE HEATS OF RENE' 41 ALLOY

Element	Heat Number (Haynes)			General Electric Co. Specification B50T59B
	TV707	TV353	TV716	
	0.010 in.	0.050 in.	0.050 in.	
Cr	19.22%	19.25%	19.05%	18.00 to 20.00%
Co	10.98	11.20	10.62	10.00 to 12.00
Mo	10.03	9.85	10.18	9.00 to 10.50
Al	1.45	1.49	1.44	1.40 to 1.60
Ti	3.03	3.15	3.12	3.00 to 3.30
Fe	1.44	0.67	1.48	5.00 max.
C	0.08	0.09	0.09	0.12 max.
Si	0.28	0.14	0.29	0.50 max.
S	0.007	0.005	0.007	0.015 max.
Mn	0.01	0.02	0.03	0.10 max.
B	0.005	0.005	0.005	0.003 to 0.010
Ni	Balance	Balance	Balance	Balance

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TABLE II

HEAT TREATMENTS OF THREE HEATS OF RENE' 41 ALLOY

(All heat treatments were preceded by a mill anneal at 1975°F, RC)

Heat Number (Haynes)	Thickness	Solution Treatment	Aging
TV707	0.010 in.	2150°F (1/2 hr) AC	1650°F (4 hrs)
TV353	0.050	1950°F (1/2 hr) RAC	1400°F (16 hrs)
TV716	0.050	2150°F (1/2 hr) RAC	1650°F (4 hrs)
General Electric Co. Specification			
B50T59C		1950°F (1/2 hr) AC	1400°F (16 hrs)
B50T59D		2150°F (1/2 hr) AC	1650°F (4 hrs)

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TABLE III

SHORT-TIME TENSILE TEST RESULTS
ON RENE' 41 ALLOY SHEET AT A SLOW STRAIN RATE

Thickness = 0.050 in.
Heat Treatment = 2150°F (1/2 hr) RAC + 1650°F (4 hrs)
Heat Number = TV716 (Haynes)

Machine = ETTM
Method of Heating = Resistance
Heating Rate = 200°F/sec
Hold Time = 5 min
Strain Rate = 0.00001 in./in./sec to YS
0.01 in./in./sec to Rupture
Gage Length = 2.0 in.

Specimen No.	Test Temperature (°F)	Proportional Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Elongation (%)	Modulus of Elasticity
479D	RT	88	109	166	14	32×10^6 psi
480D	RT	89	110	172	17	32
481D	800	85	106	154	19	28
482D	1000	84	101	147	19	27
483D	1200	83	101	148	17	26
484D	1400	82	100	147	12	24
485D	1600	40	55	92	14	18.5
486D	1800	18	21	43	19	17.5

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TABLE IV

SHORT-TIME TENSILE TEST RESULTS
ON RENE' 41 ALLOY SHEET AT A SLOW STRAIN RATE

Thickness = 0.050 in.
Heat Treatment = 1975°F (1/2 hr) RAC + 1400°F (16 hrs)
Heat Number = TV353 (Haynes)

Machine = ETTM
Method of Heating = Resistance
Heating Rate = 200°F/sec
Hold Time = 2 min
Strain Rate = 0.00001 in./in./sec to YS
0.01 in./in./sec to Rupture
Gage Length = 2.0 in.

Specimen No.	Test Temperature (°F)	Proportional Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Elongation (%)	Modulus of Elasticity
938A	RT	132.0	151.0	182.0	11	29.0×10^6 psi
939A	RT	131.0	148.0	179.0	10	29.0
940A	RT	126.0	150.0	184.0	12	30.0
951A	RT	129.0	148.0	184.0	12	30.5
960A	800	120.0	133.0	169.0	18	25.0
961A	800	123.0	138.0	165.0	15	26.0
962A	1200	109.0	130.0	161.0	15	25.0
963A	1200	107.0	132.0	166.0	17	24.0
964A	1200	110.0	129.0	163.0	20	24.0
928A	1600	40.0	67.5	106.5	6.5	18.0
929A	1600	36.0	54.7	110.5	7.5	16.0
930A	1600	30.0	49.0	104.7	6.5	17.0
931A	1800	10.1	14.7	42.5	17	12.5
945A	1800	6.0	14.0	40.5	21	12.0
970A	2000	--	2.2	13.2	32	6.5
971A	2000	--	2.4	15.6	44	7.0
972A	2000	--	3.2	16.4	28	5.5

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TABLE V

SHORT-TIME TENSILE TEST RESULTS
ON RENE' 41 ALLOY SHEET AT A SLOW STRAIN RATE

Thickness = 0.010 in.
Heat Treatment = 2150°F (1/2 hr) AC + 1650°F (4 hrs)
Heat Number = TV707 (Haynes)

Machine = ETTM
Method of Heating = Resistance
Heating Rate = 200°F/sec
Hold Time = 5 min
Strain Rate = 0.00001 in./in./sec to YS
0.01 in./in./sec to Rupture
Gage Length = 2.0 in.

Specimen No.	Test Temperature (°F)	Proportional Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Elongation (%)	Modulus of Elasticity
212E	RT	70.1	88.4	119.5	7	29.2×10^6 psi
211E	RT	62.5	84.6	121.8	9	29.6
214E	800	66.0	79.9	112.0	12	26.0
215E	800	66.3	80.0	113.0	12	27.0
216E	1000	61.0	77.8	109.9	13	25.9
217E	1000	59.0	73.0	107.0	13	26.9
218E	1200	58.4	76.0	103.9	10	24.0
219E	1200	54.0	74.1	102.0	10	24.4
220E	1400	62.0	80.8	103.0	5	21.9
221E	1400	61.0	81.8	104.0	5	24.0
222E	1600	38.4	51.9	88.0	8	19.0
223E	1600	34.0	49.5	85.0	9	19.9
224E	1800	15.8	20.6	40.5	10	14.2
225E	1800	13.0	18.0	37.3	10	14.8
226E	2000	1.9	3.0	18.3	15	11.0
227E	2000	2.2	3.1	18.2	18	9.0

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TABLE VI

SHORT-TIME TENSILE TEST RESULTS
ON RENE' 41 ALLOY SHEET AT AN INTERMEDIATE STRAIN RATE

Thickness = 0.050 in.
Heat Treatment = 2150°F (1/2 hr) RAC + 1650°F (4 hrs)
Heat Number = TV716 (Haynes)

Machine = ETTM
Method of Heating = Resistance
Heating Rate = 200°F/sec
Hold Time = 5 min
Strain Rate = 0.001 in./in./sec to YS
0.01 in./in./sec to Rupture
Gage Length = 2.0 in.

Specimen No.	Test Temperature (°F)	Proportional Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Elongation (%)	Modulus of Elasticity
487D	RT	88	112	174	18	31×10^6 psi
488D	RT	92	114	172	16	32
489D	800	83	104	155	19	29
490D	1000	88	104	153	22	27
491D	1200	85	104	150	26	26
492D	1400	78	102	144	20	25
493D	1600	66	88	112	19	22
494D	1800	38	45	59	21	19

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TABLE VII

SHORT-TIME TENSILE TEST RESULTS
ON RENE' 41 ALLOY SHEET AT AN INTERMEDIATE STRAIN RATE

Thickness = 0.050 in.
Heat Treatment = Sol. HT 1950°F (1/2 hr) RAC & Aged at 1400°F (16 hrs) AC
Heat Number = TV353 (Haynes)
Machine = ETTM
Method of Heating = Resistance
Heating Rate = 200°F/sec
Strain Rate = 0.001 in./in./sec to YS
0.01 in./in./sec to Rupture
Gage Length = 2.0 in.

Specimen No.	Test Temperature (°F)	Hold Time (min)	Proportional Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Elongation (%)	Modulus of Elasticity
923A	RT	--	134.0	151.0	185.0	12	29.5×10^6 psi
924A	RT	--	135.0	154.0	189.0	13	30.0
950A	RT	--	131.0	146.0	187.0	15	30.5
952A	800	2	111.0	131.0	166.0	15	26.0
953A	800	2	116.0	132.0	167.0	16	26.5
954A	800	2	117.0	132.0	171.0	19	27.0
955A	1200	2	108.0	128.0	163.0	18	24.0
956A	1200	2	105.0	129.0	164.0	16	25.0
957A	1200	30	110.0	129.0	163.0	16	23.0
958A	1400	2	96.0	121.0	158.0	12	22.0
959A	1400	2	102.0	123.0	158.0	13	21.0
933A	1600	2	64.0	96.0	114.0	7.5	19.5
934A	1600	2	63.0	92.0	107.0	8	18.0
935A	1600	30	60.0	89.0	108.0	8	19.0
936A	1800	2	22.0	32.0	46.0	17.5	13.0
937A	1800	2	22.0	31.0	45.0	15	12.5
932A	1800	30	17.0	23.0	35.0	19	12.5
925A	2000	2	7.0	9.0	16.5	45	7.5
926A	2000	2	8.0	9.5	16.0	51	6.5
927A	2000	30	7.0	9.0	14.0	30	8.5

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TABLE VIII

SHORT-TIME TENSILE TEST RESULTS
ON RENE' 41 ALLOY SHEET AT AN INTERMEDIATE STRAIN RATE

Thickness = 0.010 in.
Heat Treatment = 2150°F (1/2 hr) AC + 1650°F (4 hrs)
Heat Number = TV707 (Haynes)

Machine = ETTM
Method of Heating = Resistance
Heating Rate = 200°F/sec
Hold Time = 5 min
Strain Rate = 0.001 in./in./sec to Yield
0.001 in./in./sec to Rupture
Gage Length = 2.0 in.

Specimen No.	Test Temperature (°F)	Proportional Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Elongation (%)	Modulus of Elasticity
196E	RT	67.0	86.5	118.7	9	30.4×10^6 psi
197E	RT	69.0	88.7	122.5	9	30.4
X1	RT	67.0	86.4	115.0	8	29.4
X2	RT	72.0	87.0	114.0	7	29.8
198E	800	64.0	80.0	112.0	12	27.0
199E	800	62.0	81.8	119.0	13	26.2
200E	1000	61.0	79.9	109.0	11	26.5
201E	1000	60.0	78.5	108.0	11	26.0
202E	1200	56.0	76.0	104.0	10	23.0
203E	1200	51.0	77.1	106.0	10	24.0
204E	1400	52.0	77.0	105.9	7	22.0
205E	1400	54.0	79.0	107.0	6	23.1
206E	1600	44.0	71.0	85.0	8	22.5
207E	1600	45.5	72.0	86.6	8	21.4
228E	1800	18.5	30.2	38.3	12	17.7
208E	1800	25.5	36.5	43.0	13	17.0
X3	1800	24.0	33.1	41.0	9.5	16.5
X4	1800	25.0	32.0	38.1	9.5	16.3
210E	2000	7.5	8.5	14.3	20	12.2
211E	2000	7.2	8.7	14.2	18	11.9

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TABLE IX

SHORT-TIME TENSILE TEST RESULTS
ON RENE' 41 ALLOY SHEET AT A FAST STRAIN RATE

Thickness = 0.050 in.
Heat Treatment = 1975°F (1/a hr) RAC + 1400°F (16 hrs)
Heat Number = TV353 (Haynes)

Machine = ETTM
Method of Heating = Resistance
Heating Rate = 200°F/sec
Hold Time = 5 min
Strain Rate = 0.1 in./in./sec from Start to Rupture
Gage Length = 2.0 in.

Specimen No.	Test Temperature (°F)	Proportional Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Elongation (%)	Modulus of Elasticity
947A	RT	120.0	158.0	190.0	15	29.0×10^6 psi
948A	RT	110.0	148.0	179.0	15	30.0
949A	RT	113.0	156.0	183.0	16	30.0
967A	800	102.0	131.0	166.0	21	24.0
966A	800	100.0	130.0	166.0	24	23.0
965A	1200	98.0	125.0	156.0	20	22.0
968A	1200	99.0	127.0	158.0	17	21.0
969A	1200	98.0	126.0	158.0	18	22.0
973A	1600	90.0	103.0	120.0	12	16.0
974A	1600	84.0	101.0	116.0	14	17.5
975A	1600	96.0	110.0	124.0	14	16.0
976A	1800	54.0	65.0	75.0	22	12.0
977A	1800	49.0	60.0	77.0	20	10.0
978A	2000	20.0	23.5	24.5	27	7.5
979A	2000	19.0	23.0	25.0	46	9.5
980A	2000	20.0	25.0	26.5	74	8.0

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TABLE X

COMPARISON OF AVERAGE TENSILE PROPERTIES FOR RENE' 41 ALLOY SHEET SOLUTION HEAT TREATED AT 1950°F AND AGED AT 1400°F FOR 16 HOURS

Test Temperature	0.2% Yield Strength		Ultimate Strength	Elongation
	0.00001 in./in./sec	0.001 in./in./sec	0.01 in./in./sec	in 2.0 in.
RT	150.0 Ksi	150.0 Ksi	184.0 Ksi	6.5%
1000°F	129.0	129.0	165.0	8.7
1200	126.0	126.0	164.0	8
1400	108.0	122.0	158.0	6
1600	55.0	92.0	110.0	5

NOTE:
Sheet = 0.050 in. thick, (Heat TV353)

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TABLE XI

1600°F TENSILE CREEP-RUPTURE DATA FOR RENE 41' ALLOY SHEET

Heat Treatment = Sol. HT 1950°F (1/2 hr) RAC
Age 1400°F (16 hrs) AC
Heat Number = TV353

Machine = ETTM
Heating = Resistance
Sheet Thickness = 0.050 in.
Gage Length = 2.0 in.

Specimen No.	Stress Level (Ksi)	Load Extension (%)	Time to Produce Indicated Creep (sec)						Creep In 900 sec (%)	Time To Rupture (sec)	Elongation At Rupture (%)	Residual UTS (Ksi)
			0.05%	0.2%	0.5%	1.0%	2.0%	4.0%				
990A	90	0.55	--	1.3	3.7	6.6	11	16	--	18	6	--
991A	90	0.65	0.4	2.0	4.4	8.0	13	16	--	17.5	4.5	--
984A	90	0.65	0.5	1.5	6.0	10.0	16	22	--	26	7	--
992A	75	0.20	2.0	9	25	44	71	101	--	105	5.5	--
993A	75	0.25	3.0	14	31	54	82	113	--	117	5.5	--
994A	75	0.25	1.4	10	25	40	68	96	--	104	6	--
995A	60	0.25	10	71	173	281	403	534	--	545	5	--
996A	60	0.25	11	69	190	316	454	595	--	617	5	--
997A	60	0.27	11	59	157	260	370	495	--	545	6	--
3B	45	0.22	40	320	950	--	--	--	0.49	900+	7.5	110.0
998A	45	0.22	35	285	710	--	--	--	0.69	900+	8	99
999A	45	0.25	22	217	590	850	--	--	0.13	900+	7	92
1B	45	0.22	20	270	807	--	--	--	0.55	900+	6.5	105
2B	45	0.22	34	260	--	--	--	--	--	--	--	--
2B1	45	0.22	34	320	--	--	--	--	--	--	--	--
987A	30	0.10	90	780	--	--	--	--	0.22	900+	7.0	100.5
988A	30	0.10	82	935	--	--	--	--	0.19	900+	6.5	100.5
989A	30	0.10	55	960	--	--	--	--	0.19	900+	6.5	104.0

TABLE XII

1800°F TENSILE-CREEP RUPTURE DATA FOR RENE' 41 ALLOY SHEET

Heat Treatment = Sol. HT 1950°F (1/2 hr) RAC
Age 1400°F (16 hrs) AC
Heat Number = TV353

Machine = ETTM
Heating = Resistance
Sheet Thickness = 0.050 in.
Gage Length = 2.0 in.

Specimen No.	Stress Level (Ksi)	Load Extension (%)	Time to Produce Indicated Creep (sec)							Creep In 900 sec (%)	Time To Rupture (sec)	Elongation At Rupture (%)	Residual UTS (Ksi)
			0.05%	0.2%	0.5%	1.0%	2.0%	4.0%	6.0%				
5B	34	0.25	0.5	3.0	8.5	18	34	60	78	--	92	11	--
6B	34	0.3	--	1.0	3.0	5.5	10	19	23	--	42	17	--
7B	34	0.3	--	1.5	3.0	6.4	12.5	22	32	--	52	16	--
8B	28	0.2	1.4	8.5	23	42	70	108	134	--	150	10	--
9B	28	0.25	--	2.1	6	17	42	75	100	--	119	12	--
10B	28	0.2	1.0	4.0	14	29	60	113	148	--	178	14	--
24B	28	0.2	1.1	6.8	17.5	34	63	102	112	--	160	12	--
11B	22	0.15	5.2	36	113	225	358	513	609	--	673	10.5	--
12B	22	0.16	8.8	43	125	220	346	486	578	--	657	13	--
13B	22	0.15	2.0	34	68	115	178	254	285	--	306	12	--
14B	22	0.1	1.0	9.2	34	74	125	182	212	--	255	12	--
15B	22	0.2	4.6	18	44	82	144	225	285	--	359	12	--
25B	22	0.17	4.0	25	71	130	212	305	359	--	411	12.5	--
17B	18	0.22	8.4	112	275	478	725	--	--	2.87	900+	13	35.1
18B	18	0.10	6.0	93	255	481	782	--	--	2.75	900+	17	35.0
23B	18	0.15	18	113	249	426	650	--	--	3.7	900+	15	34.1
20B	10	0.05	44	290	--	--	--	--	--	0.34	900+	20	32.3
21B	10	0.05	18	360	--	--	--	--	--	0.31	900+	19	34.4
22B	10	0.05	20	297	--	--	--	--	--	0.29	900+	19	33.0

THE Vanguard FOUNDATION
VAN NUYS, CALIFORNIA
REPORT PR 281-19-1

TABLE XIII

2000°F TENSILE CREEP-RUPTURE DATA FOR RENE' 41 ALLOY SHEET

Heat Treatment = Sol. HT 1950°F (1/2 hr) RAC
Age 1400°F (16 hrs) AC
Heat Number = TV353

Machine = ETTM
Heating = Resistance
Sheet Thickness = 0.050 in.
Gage Length = 2.0 in.

Specimen No.	Stress Level (Ksi)	Load Extension (%)	Time to Produce Indicated Creep (sec)							Creep In 900 sec (%)	Time To Rupture (sec)	Elongation At Rupture (%)	Residual UTS (Ksi)
			0.05%	0.2%	0.5%	1.0%	2.0%	4.0%	6.0%				
26B	10	0.25	0.2	0.7	1.2	2.6	5.3	11	16	--	62	42	--
27B	10	0.2	0.3	0.8	1.5	2.8	5.7	12	20	--	71	41	--
28B	10	0.25	--	0.7	1.5	2.4	4.7	8.5	13	--	58	43	--
29B	8	0.025	0.5	1.6	4.5	9.8	20	41	62	--	186	32	--
30B	8	0.035	0.5	2.2	5.2	10	21	41	63	--	178	32	--
31B	8	0.025	0.8	2.0	4.5	8.5	18	36	53	--	171	32	--
32B	6	0.03	1.3	5.7	16	34	70	146	223	--	762	33	--
33B	6	0.04	1.2	11.0	19	42	89	194	300	--	839	30	--
34B	6	0.03	1.4	9.7	32	70	155	334	500	11.5	900+	35	13.1
38B	6	0.1	1.2	5.4	18	38	79	165	244	--	605	36	--
35B	4	0.02	5.2	40	120	275	610	--	--	2.89	900+	30	13.5
36B	4	0.02	3.2	28	100	237	520	--	--	3.03	900+	37	13.5
37B	4	0.02	3.8	52	200	420	--	--	--	1.8	900+	48	14.4
40B	4	0.01	5.0	45	175	350	650	--	--	2.86	900+	30	13.4
41B	2	--	Heat Malfunction								---	--	--
42B	2	--	1620	--	--					0.13	2220+	--	--
43B	2	--	220	1050	--					0.33	2915+	--	--

TABLE XIV

CREEP-RUPTURE DATA FOR RENE' 41 ALLOY SHEET

Heat Treatment = Sol. HT 2150°F (1/2 hr) AC
Age 1650°F (4 hrs) AC
Heat Number = TV716
Machine = Furnace Heating
Arc Weld
Sheet Thickness = 0.050 in.

Specimen No.	Stress Level (Ksi)	Test Temperature (°F)	Time to Produce Indicated Creep (min)					Time to Rupture (min)	Elongation in 2 in. (%)
			0.05%	0.2%	0.5%	1.0%	2.0%		
464D	65	1400	660	1860	3060	--	--	3860	--
466D	65	1400	300	1290	2340	3156	3910	3984	--
500D	80	1400	90	198	333	482	684	729	--
513D	34	1400	--	--	--	--	--	No creep 3930	--
514D	36	1400	--	--	--	--	--	No creep 5334	--
459D	20	1600	444	2070	3828	5200	6216	6252	--
465D	28	1600	432	1000	1620	--	--	2136	--
517D	17	1600	3120	4980	7980	--	--	10,236	--
516D	15	1600	2400	4800	8010	14,520	--	15,534	1
502D	28	1600	24	750	1360	1,896	2010	2,376	9
455D	10	1700	1080	2190	4140	7380	12,636	20,160	3
457D	23	1700	75	300	516	685	855	1,150	8
518D	10	1700	1152	3120	6600	10,800	--	11,340	1
519D	12	1700	1920	3120	4800	6,660	--	11,436	--
467D	6	1800	276	1164	2400	3530	6300	10,893	7
468D	11	1800	320	624	960	--	--	972	--
520D	6	1800	660	1830	3450	5160	7610	9,960	3
521D	8	1800	30	300	780	1270	1900	3,300	9

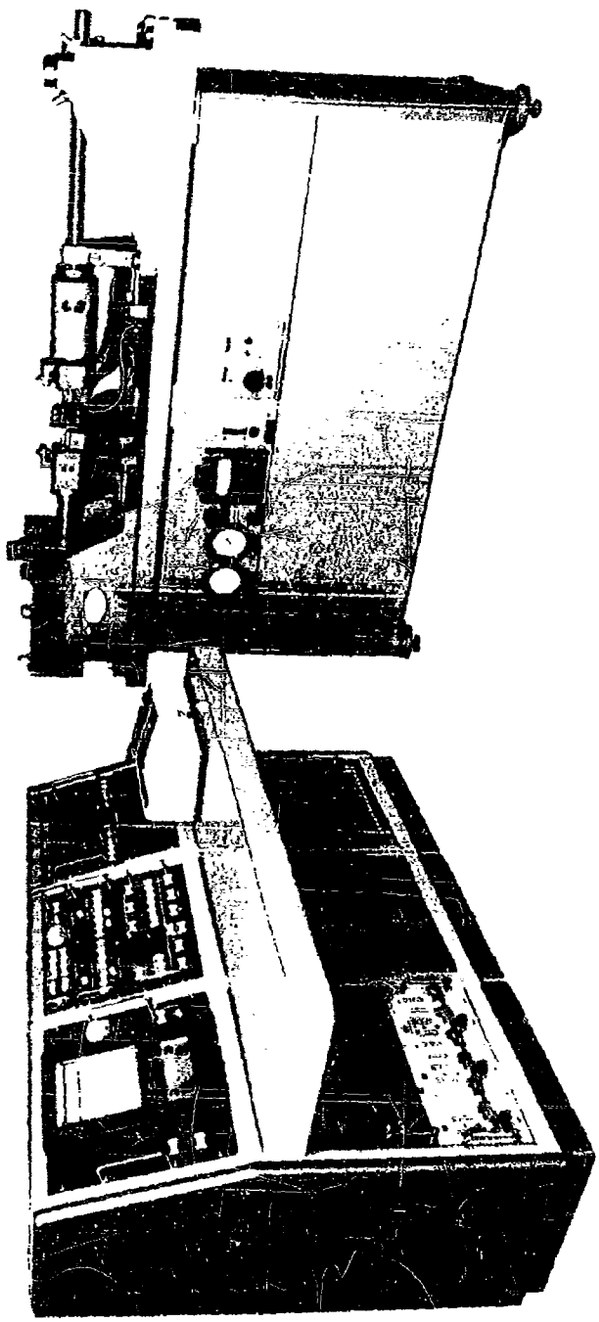

FIGURE 1 - The Marquardt TM-1A Elevated Temperature Test Machine Assembly

CA 2936-2

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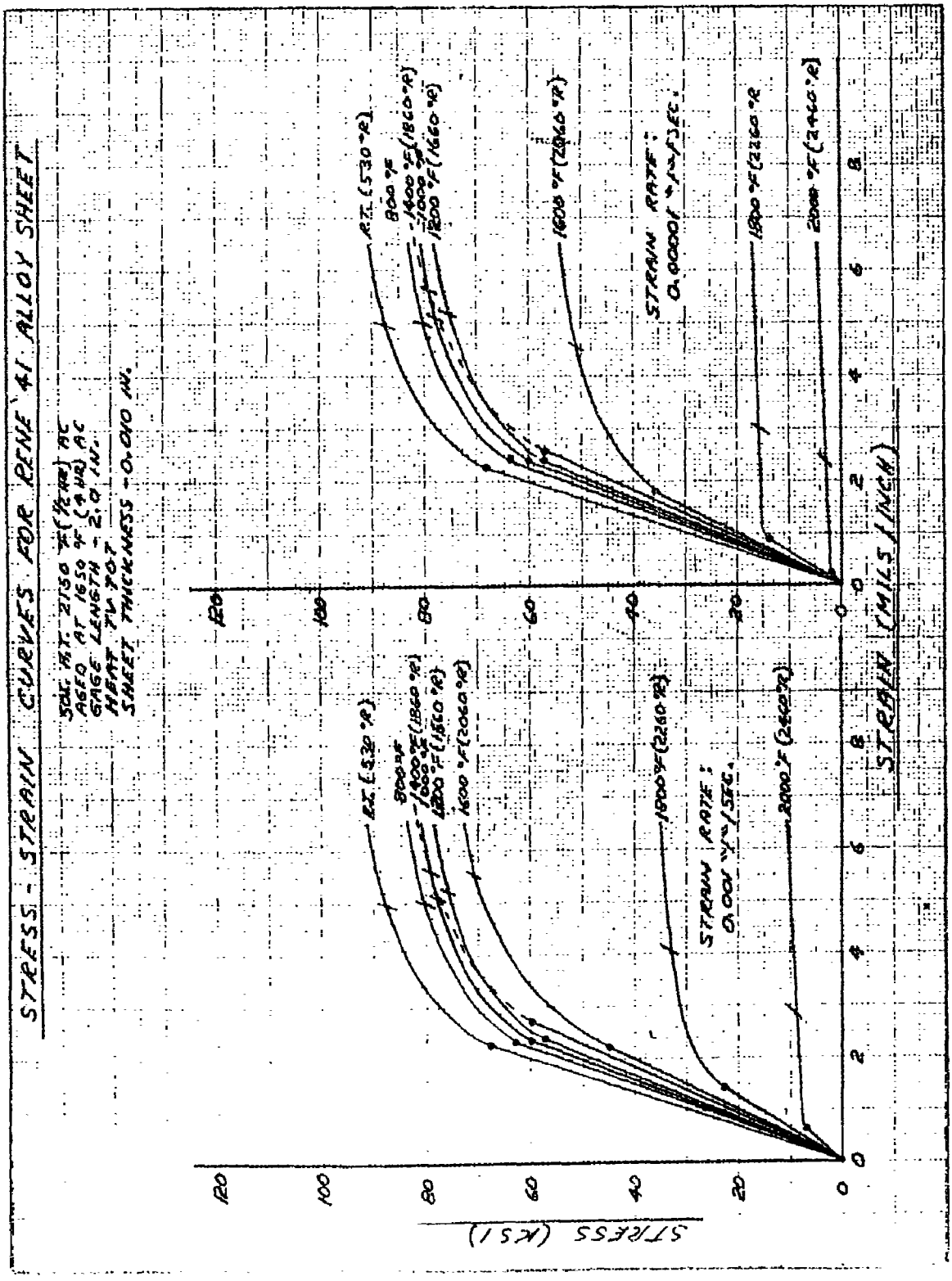
STRESS - STRAIN CURVES FOR RENE' 41 ALLOY SHEET
SOLN. HT. 2150 °F (½ HR) AC
AGED AT 1650 °F (4 HR) AC
GAGE LENGTH = 2.0 IN.
HEAT TV 707
SHEET THICKNESS = 0.040 IN.
RT (530 °F)
800 °F
1400 °F (1860 °F)
1600 °F (2060 °F)
STRAIN RATE: 0.0001 IN/IN/SEC.
1800 °F (2260 °F)
2000 °F (2460 °F)
STRAIN RATE: 0.001 IN/IN/SEC.
STRESS (KSI)
STRAIN (MILS/INCH)

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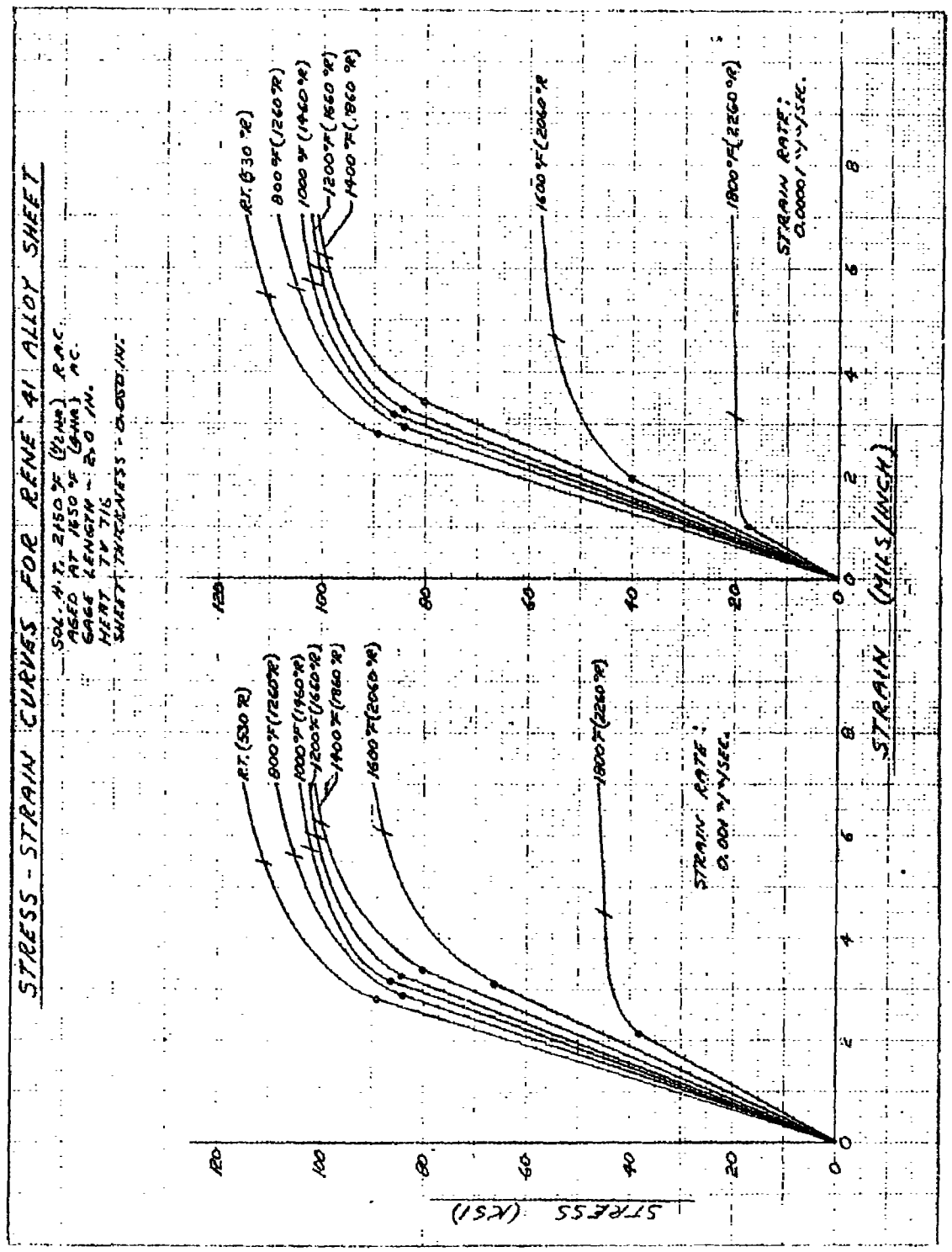
STRESS - STRAIN CURVES FOR RENE' 41 ALLOY SHEET
SOL. H.T. 2150 °F (½ HR.) A.C.
AGED AT 1650 °F (4 HR.) A.C.
GAGE LENGTH = 2.0 IN.
HEAT TV 715
SHEET THICKNESS = 0.050 IN.
R.T. (530 °F)
800 °F (1260 °F)
1000 °F (1460 °F)
1200 °F (1660 °F)
1400 °F (1860 °F)
1600 °F (2060 °F)
1800 °F (2260 °F)
STRAIN RATE: 0.005 "/"/SEC.
STRAIN RATE: 0.0001 "/"/SEC.
STRESS (KSI)
STRAIN (INCH/INCH)

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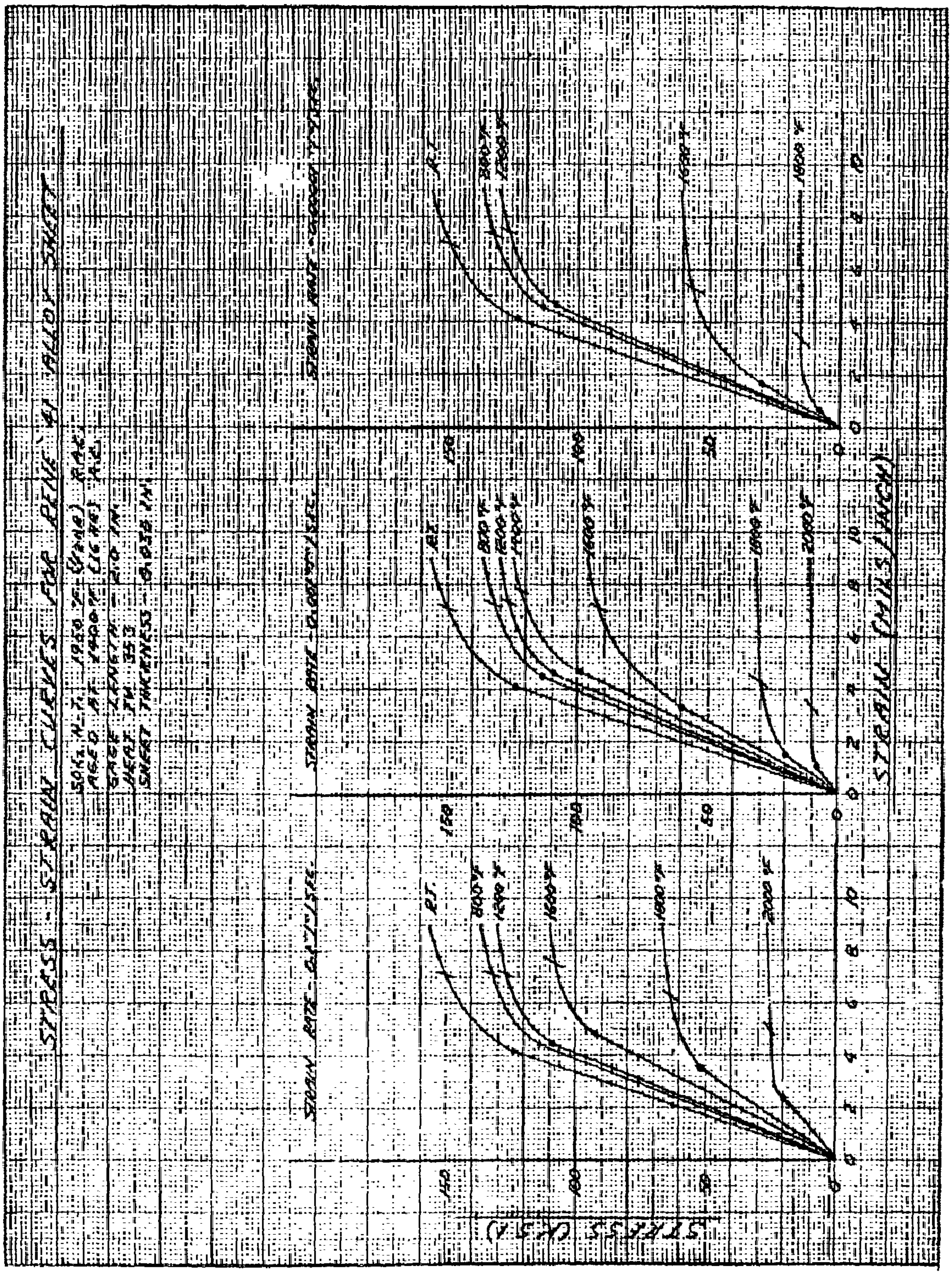
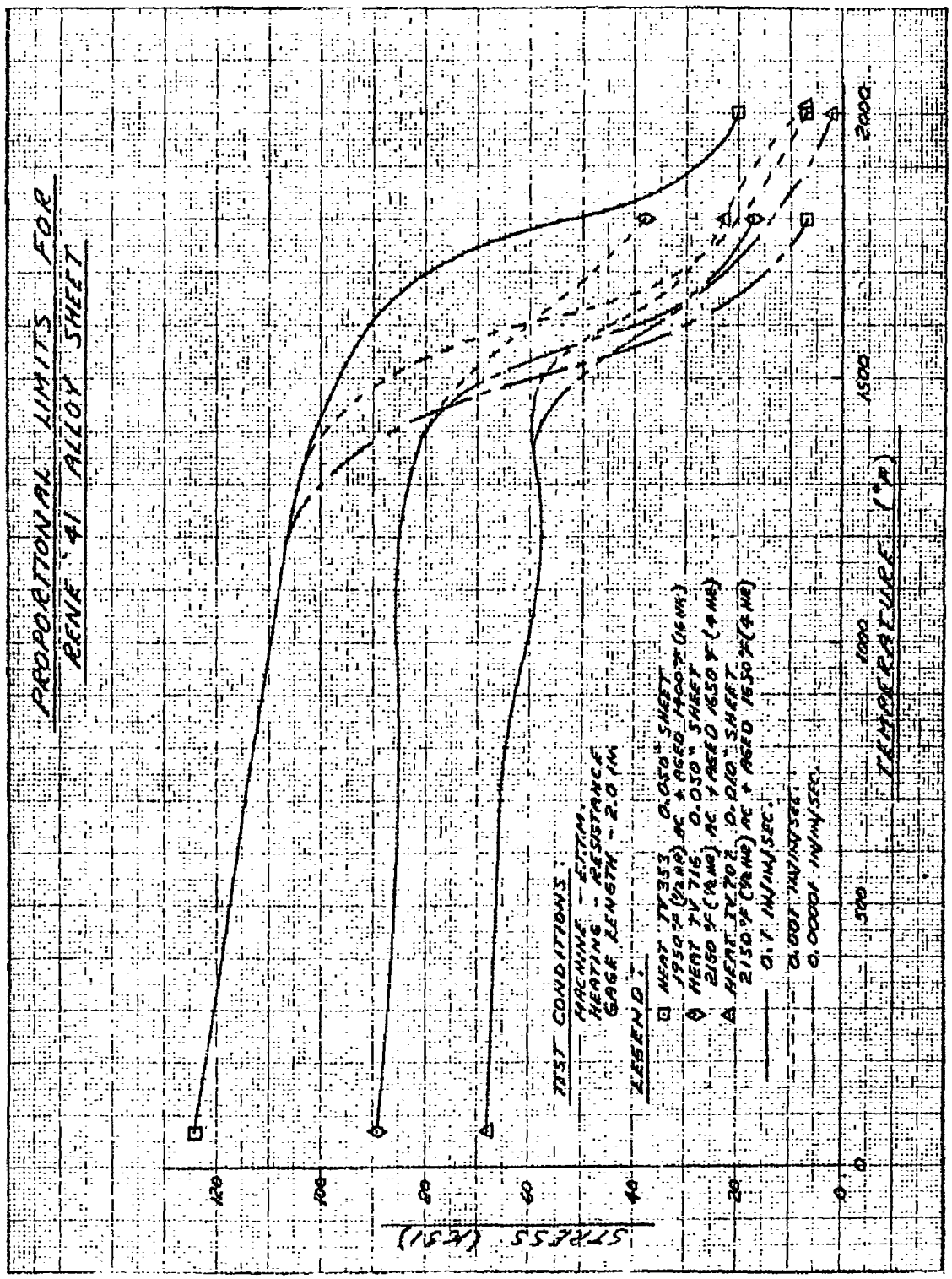
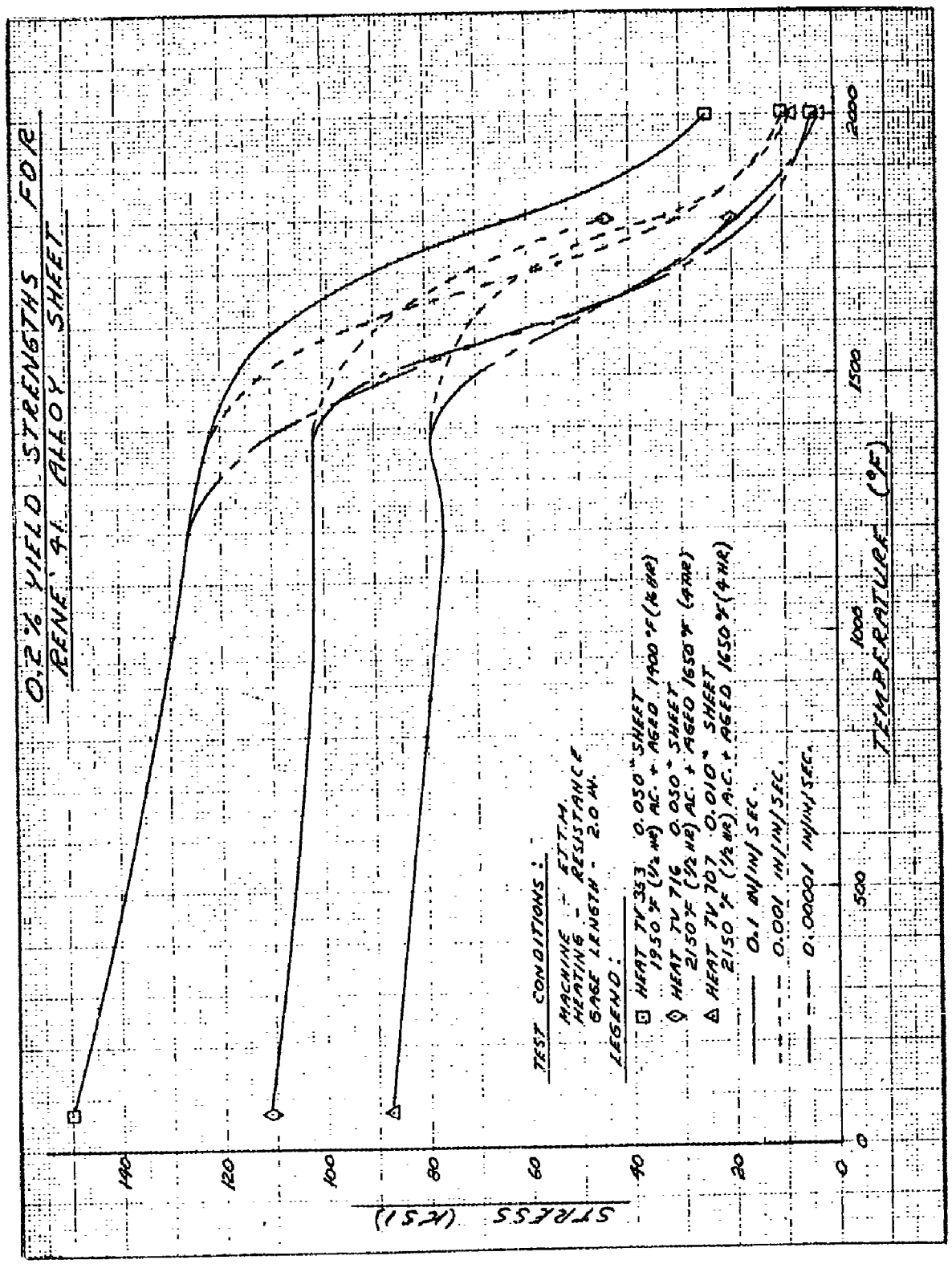

STRESS - STRAIN CURVES FOR RENE' 41 ALLOY SHEET
SOL. H.T. 1950°F (½ HR) R.A.C.
AGED AT 1400°F (16 HR) A.C.
GAGE LENGTH - 2.0 IN.
HEAT NO. 353
SHEET THICKNESS - 0.035 IN.
STRESS (K.S.I.)
STRAIN (MILS/INCH)
R.T.
800°F
1200°F
1400°F
1600°F
1800°F
2000°F


PROPORTIONAL LIMITS FOR
RENE' 41 ALLOY SHEET
TEST CONDITIONS:
MACHINE - ESTIM.
HEATING - RESISTANCE
GAGE LENGTH - 2.0 IN
LEGEND:
MAT'L TY353 0.050" SHEET
1950°F (1066°C) 4hr. + AGED 1400°F (760°C)
◇ HEAT TY715 0.050" SHEET
250 ksi (1724 MPa) AS AGED 1650 ksi (1138 MPa)
△ HEAT TY702 0.010" SHEET
215 ksi (1482 MPa) AS AGED 1650 ksi (1138 MPa)
0.1% YIELD STRENGTH
0.2% YIELD STRENGTH
STRESS (ksi)
STRESS (MPa)
STRAIN (%)
STRAIN (in/in)

M.C A673


0.2% YIELD STRENGTHS FOR
RENE' 41 ALLOY SHEET
TEST CONDITIONS :-
MACHINE - SATEC
HEATING - RESISTANCE
GAGE LENGTH - 2.0 IN.
LEGEND :-
□ HEAT TV 353 0.050" SHEET
1950 °F (1 HR) AC. + AGED 1400 °F (16 HR)
◇ HEAT TV 716 0.030" SHEET
2150 °F (½ HR) AC. + AGED 1650 °F (4 HR)
△ HEAT TV 707 0.010" SHEET
2150 °F (½ HR) A.C. + AGED 1650 °F (4 HR)
0.1 IN/IN/SEC.
0.001 IN/IN/SEC.
0.00001 IN/IN/SEC.
STRESS (KSI)
TEMPERATURE (°F)
140
120
100
80
60
40
20
0
0
500
1000
1500
2000

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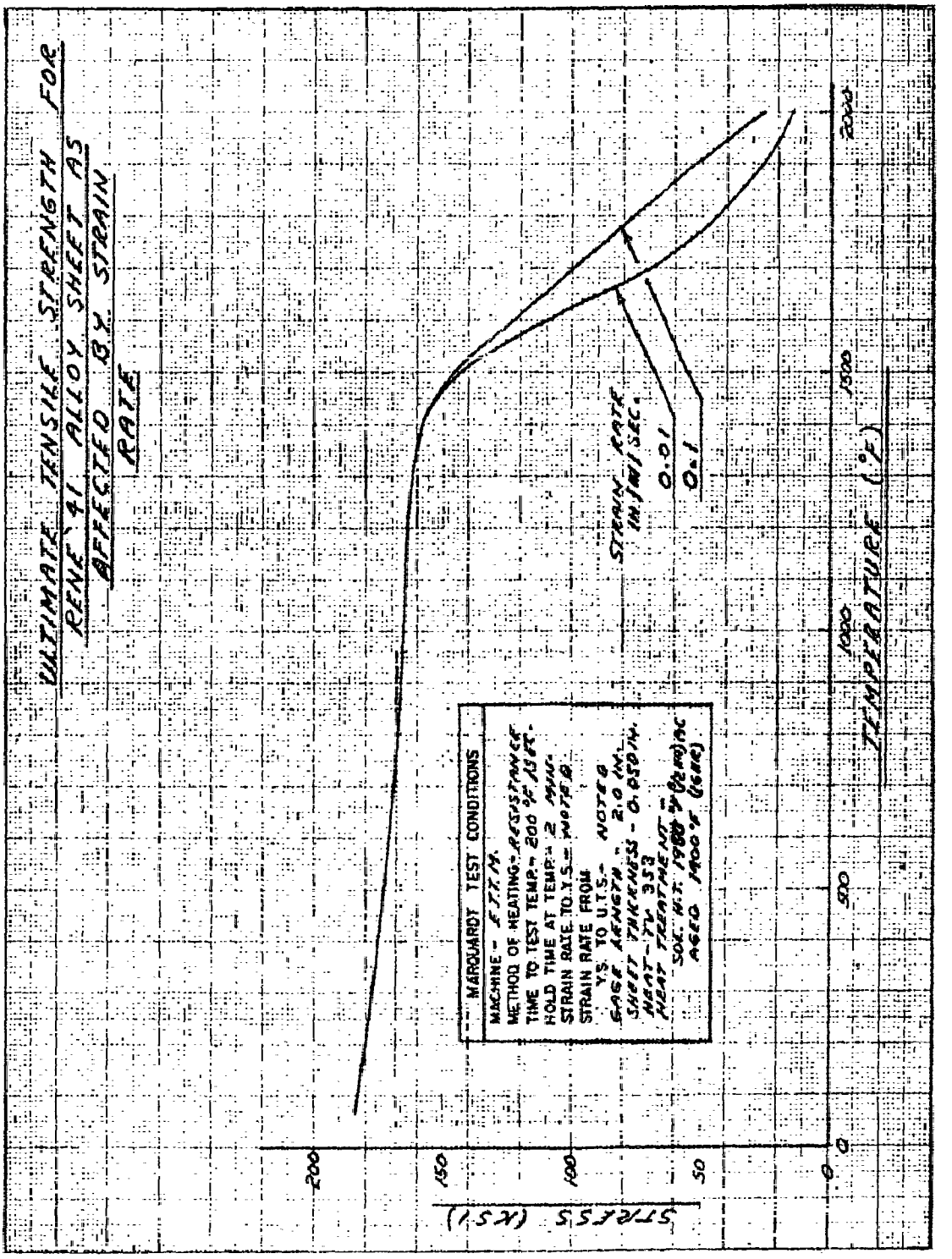
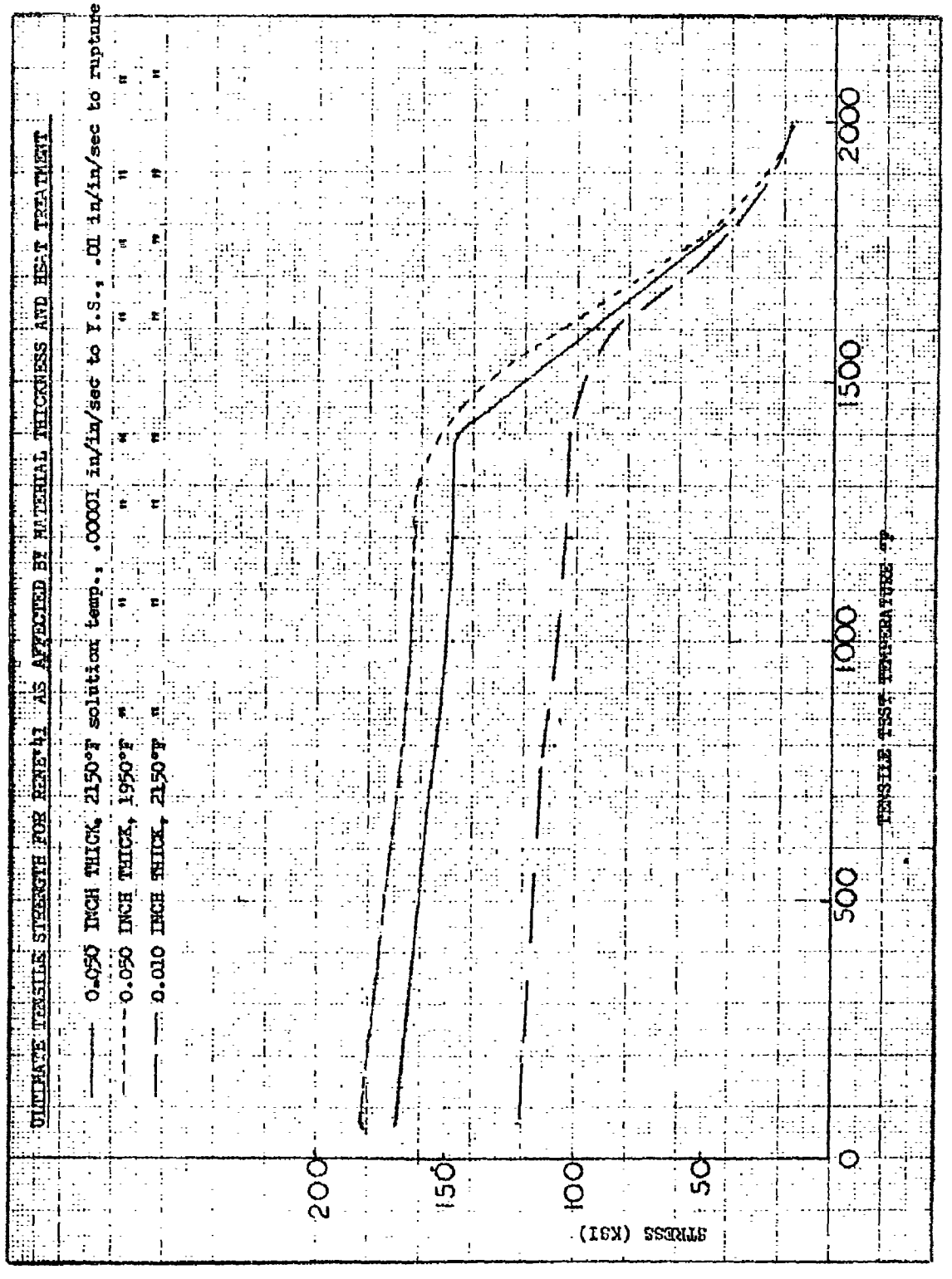

ULTIMATE TENSILE STRENGTH FOR
RENE 41 ALLOY SHEET AS
AFFECTED BY STRAIN
RATE
MARQUARDT TEST CONDITIONS
MACHINE - FERRY
METHOD OF HEATING - RESISTANCE
TIME TO TEST TEMP. - 200 °F/SEC.
HOLD TIME AT TEMP. - 2 MIN.
STRAIN RATE TO Y.S. - NOTED
STRAIN RATE FROM
Y.S. TO U.T.S. - NOTED
GAGE LENGTH - 2.0 IN.
SHEET THICKNESS - 0.050 IN.
HEAT-LOT 353
HEAT TREATMENT -
SOL. H.T. 1900 °F (1038°C)
AGED 1400 °F (760°C)
STRAIN RATE
IN/IN/SEC.
0.01
0.1
STRESS (KSI)
TEMPERATURE (°F)
0
50
100
150
200
500
1000
1500
2000

MAC A673


ULTIMATE TENSILE STRENGTH FOR RENE'41 AS AFFECTED BY MATERIAL THICKNESS AND HEAT TREATMENT
0.050 INCH THICK, 2150°F solution temp., .0000I in/in/sec to Y.S., .01 in/in/sec to rupture
0.050 INCH THICK, 1950°F " " " " " "
0.010 INCH THICK, 2150°F " " " " " "
STRESS (KSI)
200
150
100
50
0
500
1000
1500
2000
TENSILE TEST TEMPERATURE °F

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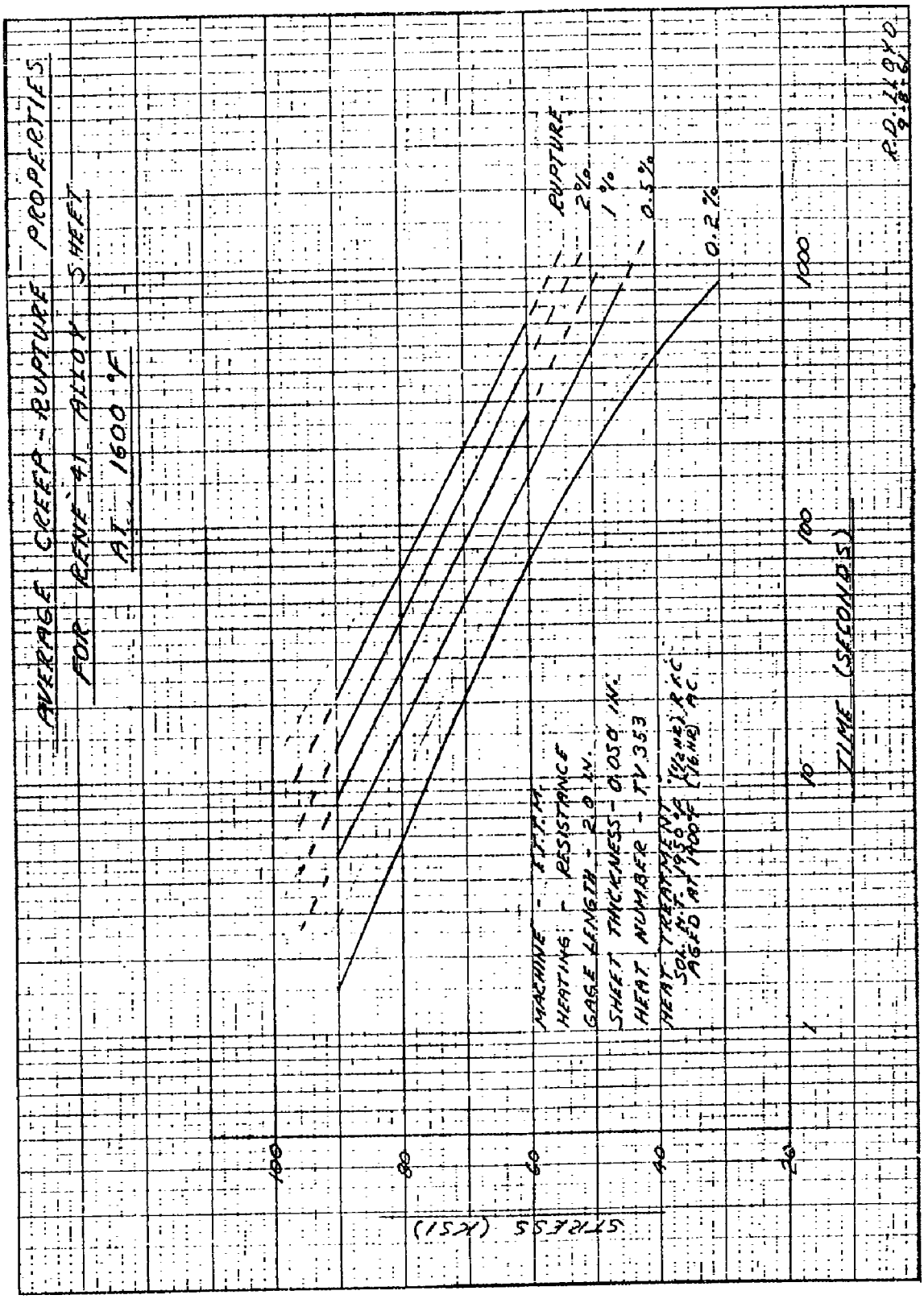
AVERAGE CREEP-RUPTURE PROPERTIES
FOR RENE' 41 ALLOY SHEET
AT 1600°F
RUPTURE
2%
1%
0.5%
0.2%
MACHINE - T.T.M.
HEATING - RESISTANCE
GAGE LENGTH - 2.0 IN.
SHEET THICKNESS - 0.050 IN.
HEAT NUMBER - TV 353
HEAT TREATMENT
SOL. A.T. 1950°F (1066°C) AC
AGED AT 1400°F (760°C) AC
TIME (SECONDS)
1
10
100
1000
100
80
60
40
20
(15%) 55 72 45
R.D. 4-9-60

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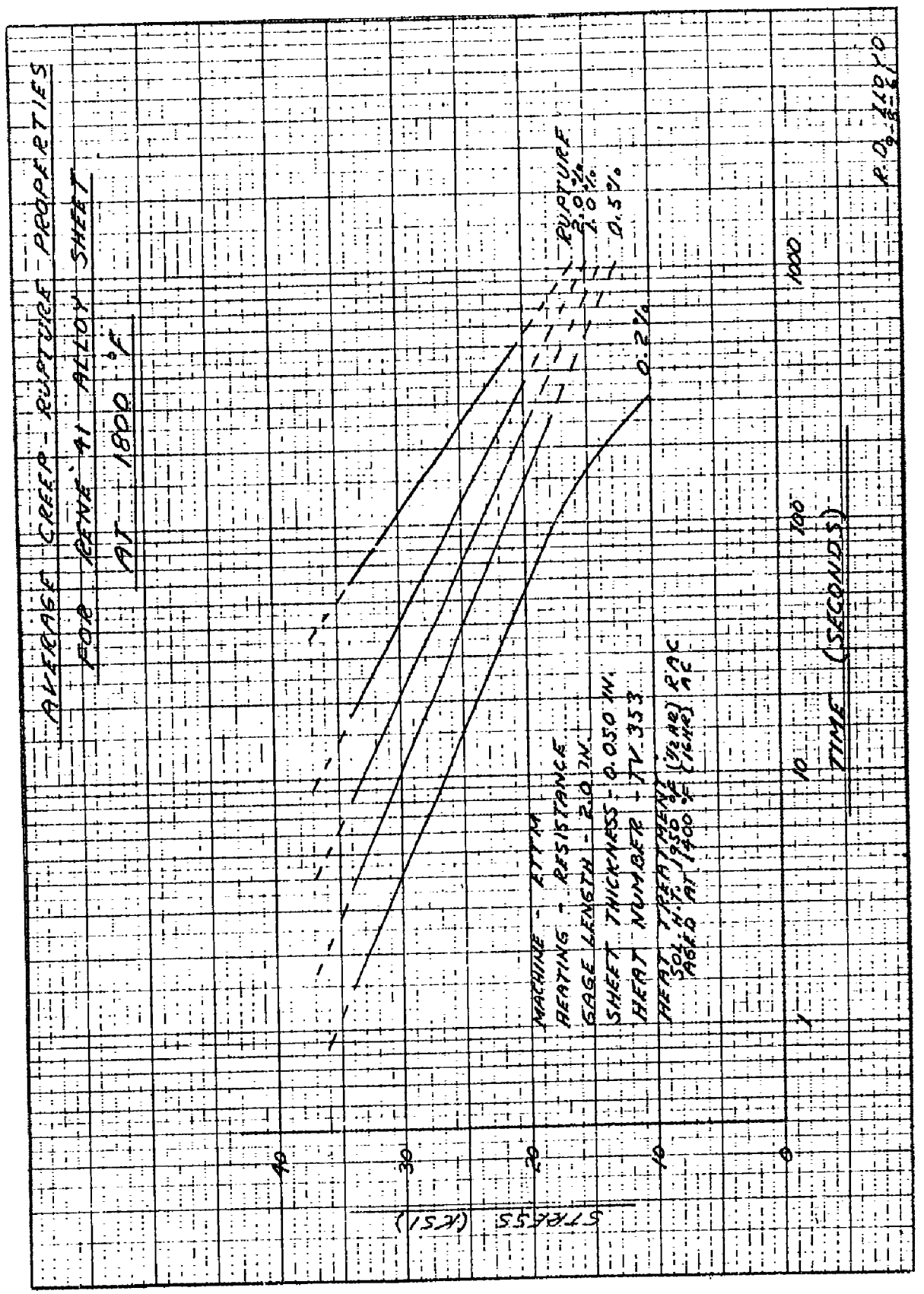

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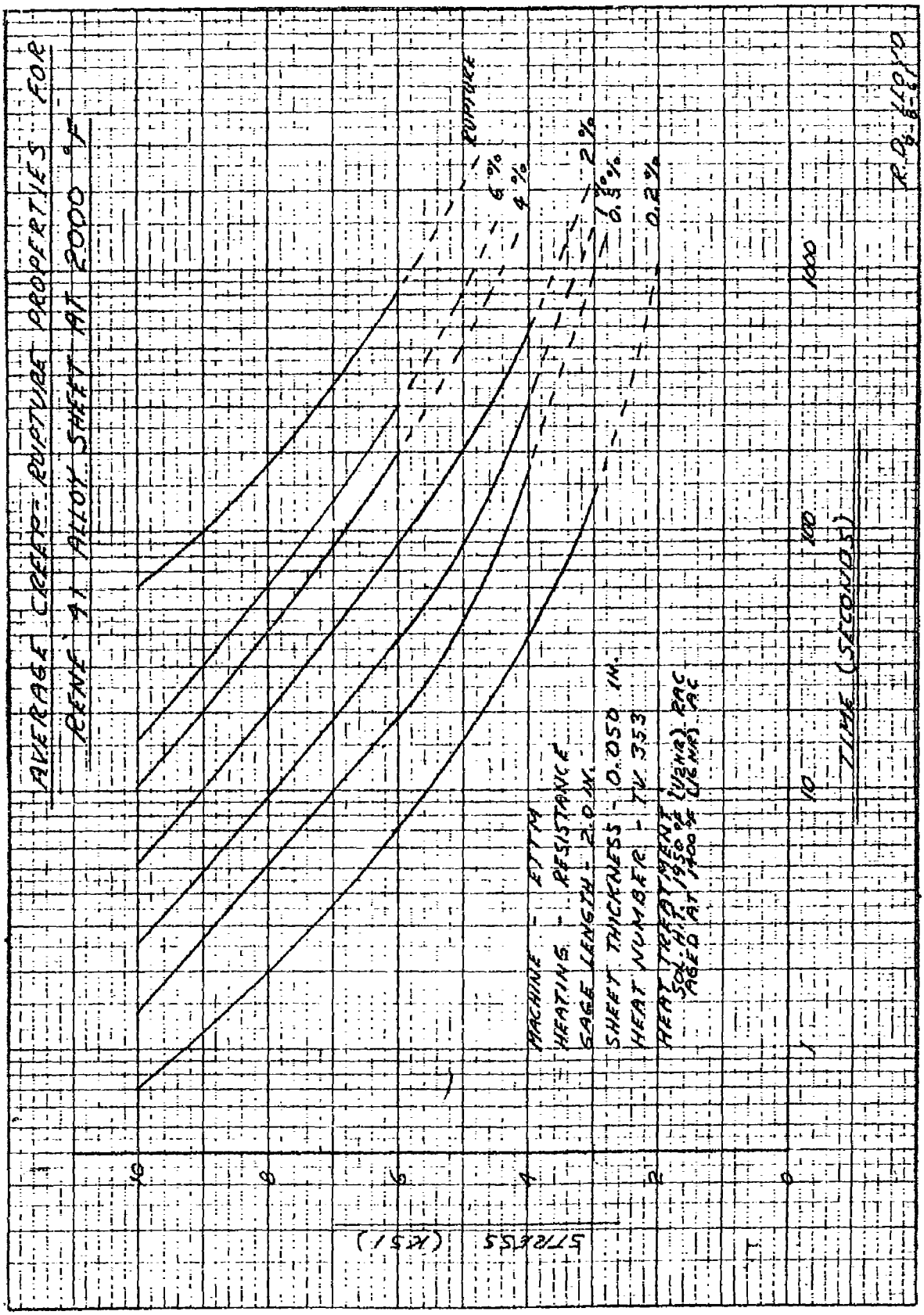
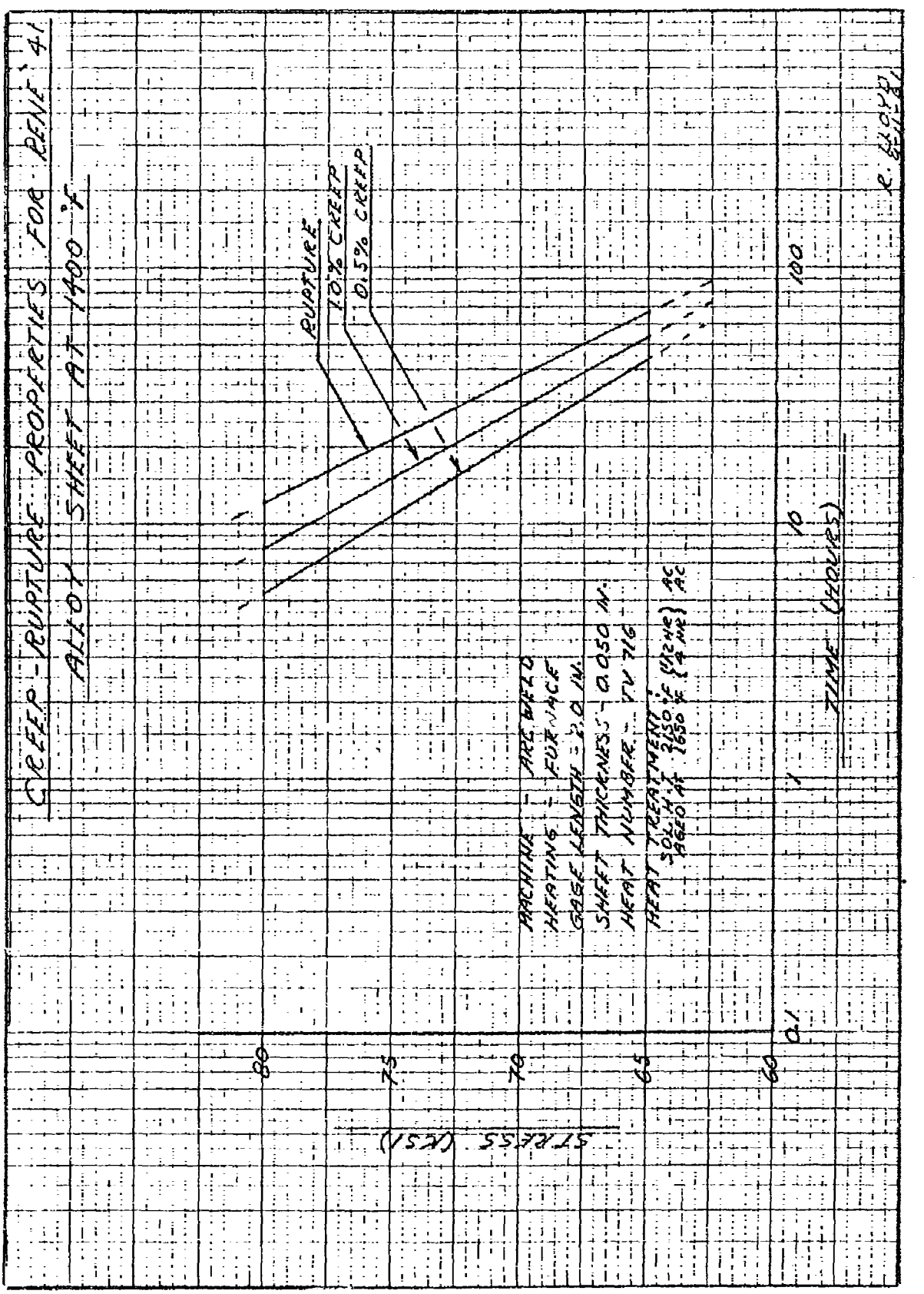
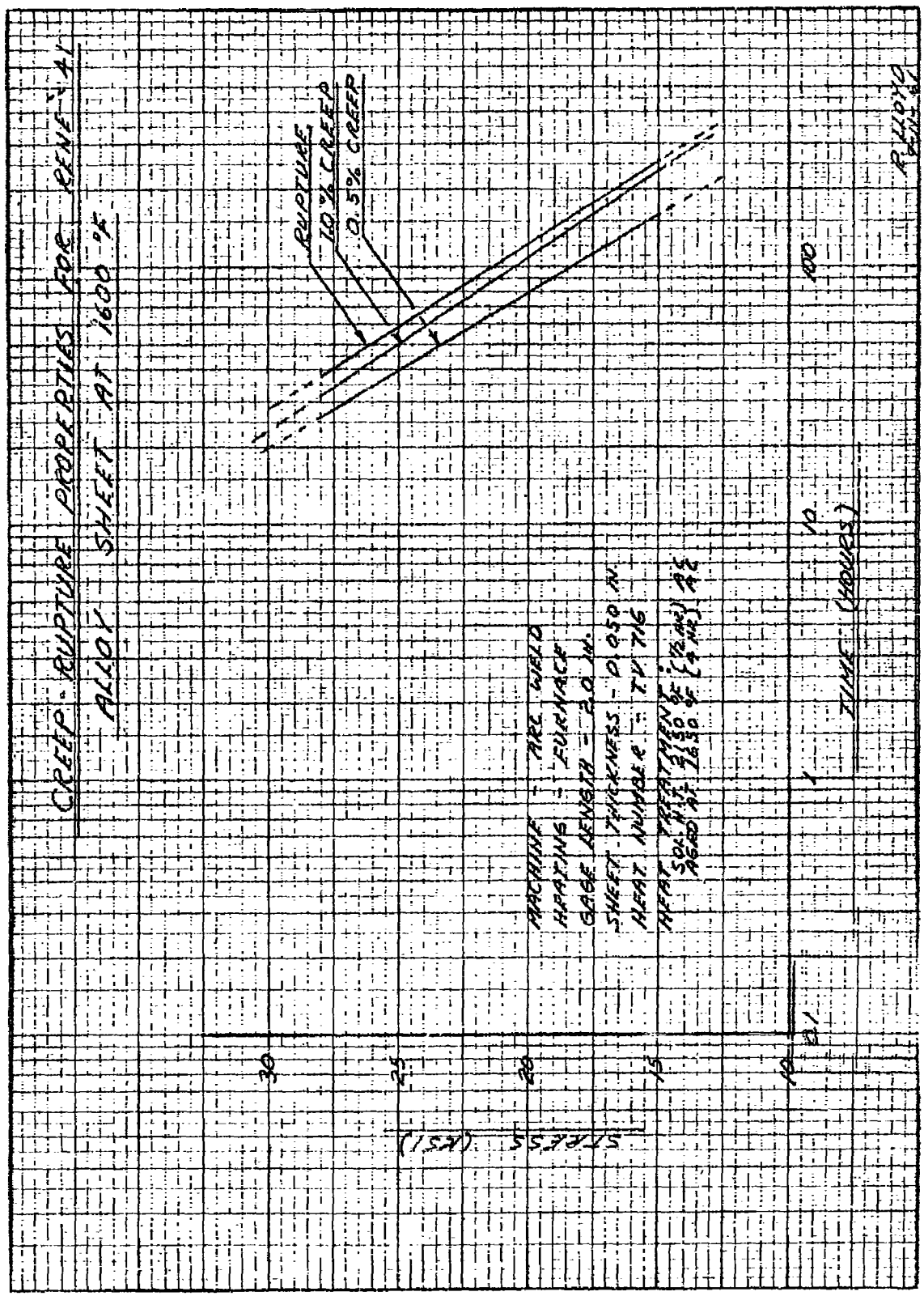
FIGURE 10


AVERAGE CREEP - RUPTURE PROPERTIES FOR
RENE' 41 ALLOY SHEET AT 2000 °F
RUPTURE
6%
4%
2%
1%
0.5%
0.2%
MACHINE - ETTA
HEATING - RESISTANCE
GAGE LENGTH - 2.0 IN.
SHEET THICKNESS - 0.050 IN.
HEAT NUMBER - TW 353
HEAT TREATMENT (VSMA) PAC
SOL. H.T. 1950°F (VSMA) PAC
AGED AT 1400°F (VSMA) PAC
STRESS (KSI)
TIME (SECONDS)
10
8
6
4
2
0
1
10
100
1000
R-8-61-10

MAC A673


CREEP-RUPTURE PROPERTIES FOR RENE' 41
ALLOY SHEET AT 1400 °F
RUPTURE
10% CREEP
0.5% CREEP
STRESS (KSI)
TIME (HOURS)
MACHINE - ARC BRZD
HEATING - FURNACE
GAGE LENGTH = 2.0 IN.
SHEET THICKNESS - 0.050 IN.
HEAT NUMBER - TV 716
HEAT TREATMENT -
SOLN AT 2150 °F (1½ HR) AC
AGED AT 1650 °F (4 HR) AC
R. GLOVER

MAC A673


CREEP & RUPTURE PROPERTIES FOR
ALLOY - SHEET - 91 1600 °F
RUPTURE
10% CREEP
0.5% CREEP
STRESS (KSI)
TIME (HOURS)
MACHINE - ARC WELD
HEATING - FURNACE
GAGE LENGTH - 2.0 IN.
SHEET THICKNESS - .050 IN
HEAT NUMBER - TV 716
HEAT TREATMENT
SOLUTION
AGED AT

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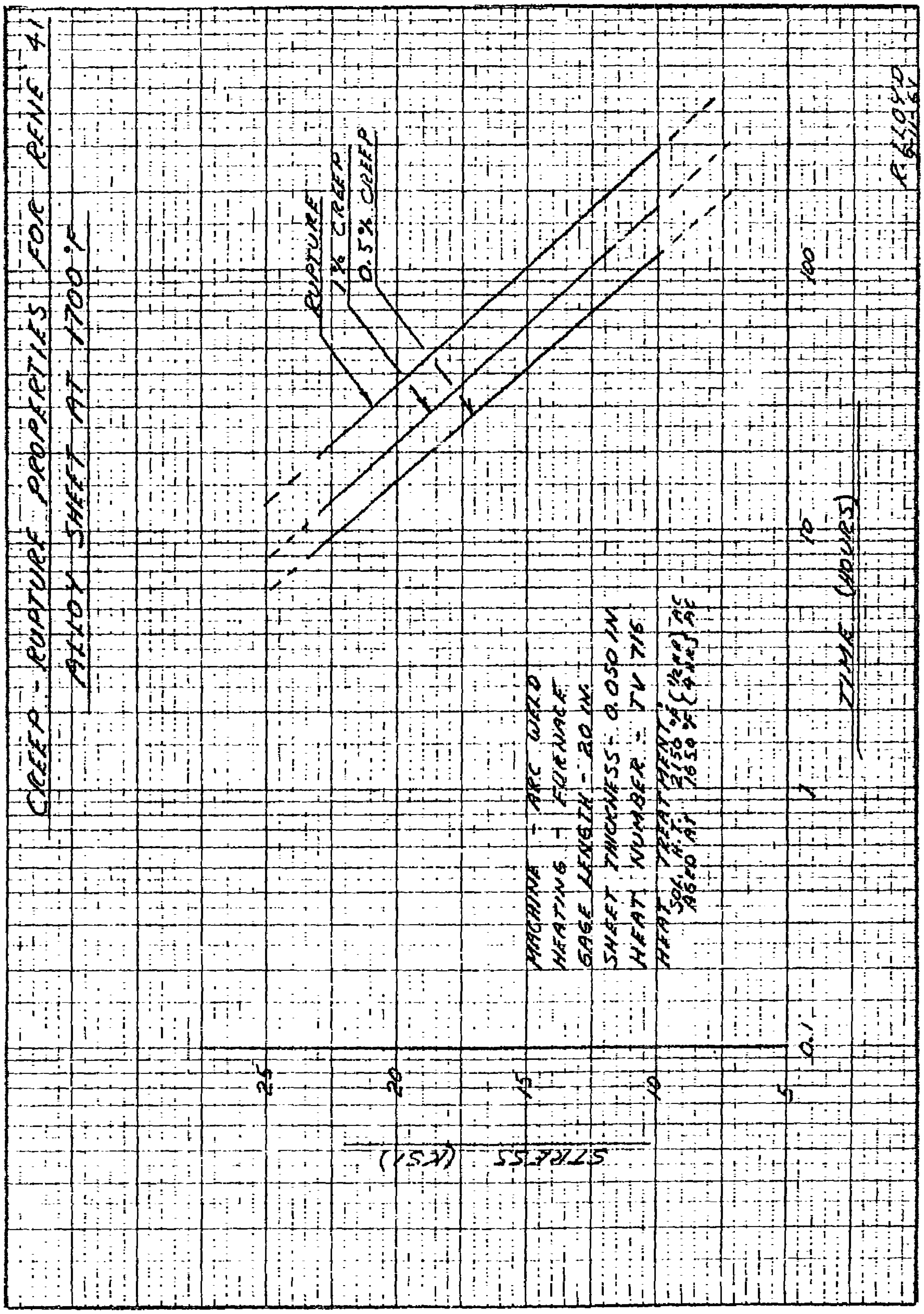
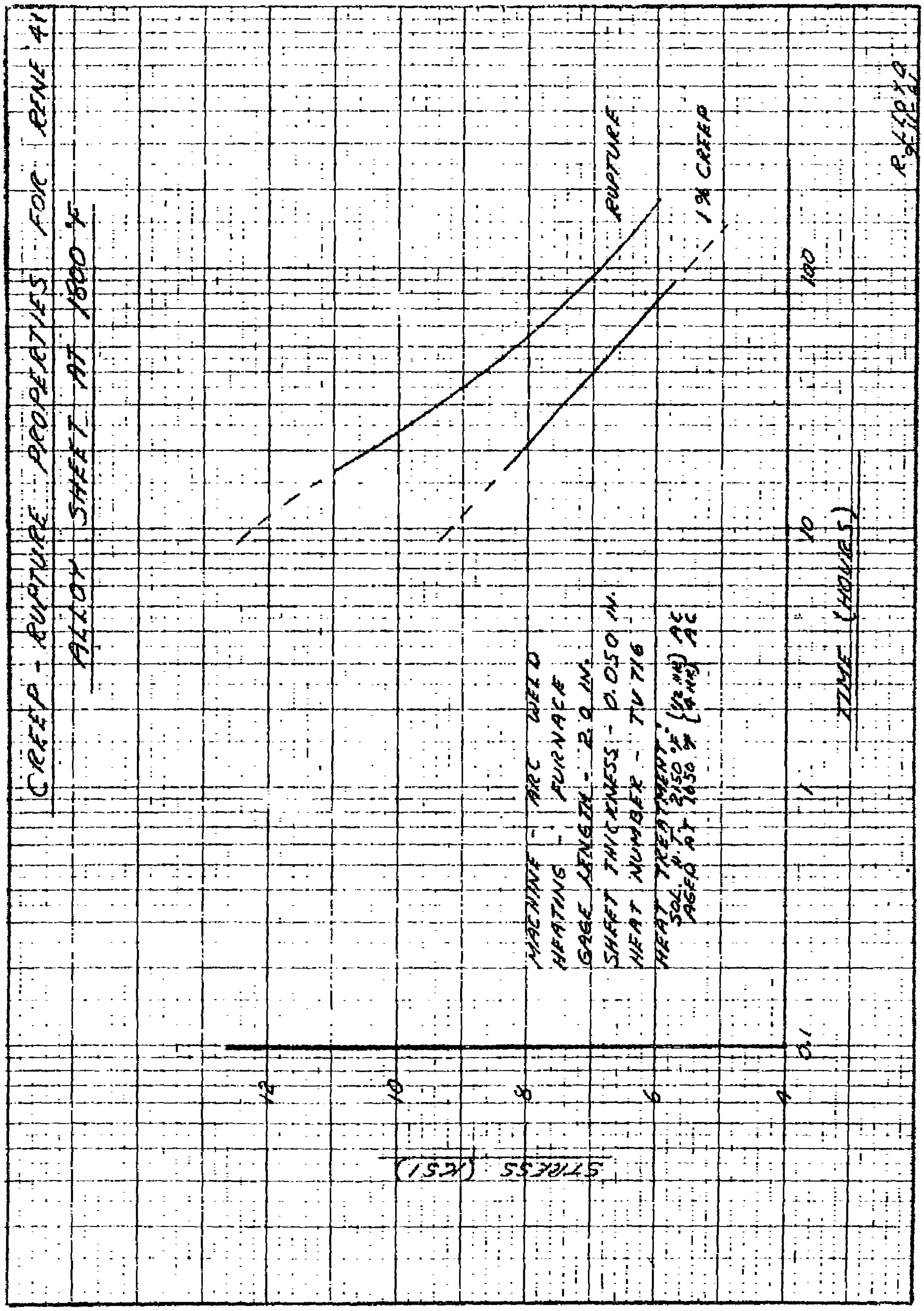

CREEP - RUPTURE PROPERTIES FOR RENE 41
ALLOY SHEET AT 1700°F
RUPTURE
1% CREEP
0.5% CREEP
MACHINE - ARC WELD
HEATING - FURNACE
GAGE LENGTH - 2.0 IN
SHEET THICKNESS - 0.050 IN
HEAT NUMBER - TV 716
25
20
15
10
5
STRESS (KSI)
0.1
1
10
100
TIME (HOURS)


CREEP - RUPTURE PROPERTIES FOR RENE 41
ALLOY SHEET AT 1800 °F
RUPTURE
1% CREEP
MACHINE - ARC WELD
HEATING - FURNACE
GAGE LENGTH - 2.0 IN.
SHEET THICKNESS - 0.050 IN.
HEAT NUMBER - TV 716
HEAT TREATMENT:
SOL. H.T. 2150 °F (1/2 HR) AC
AGED AT 1650 °F (4 HRS) AC
12
10
8
6
4
STRESS (KSI)
0.1
1
10
100
TIME (HOURS)

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